Institution of Electrical Engineers.

Pioneers

13. Heinrich Rudolf Hertz (1857-1894) and the discovery of radio waves.

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Because he died young we think of Hertz as a 19th century scientist, a man from long ago. It is a salutary thought that, had he lived into his eighties, he could have ended his days in a Nazi concentration camp.

Heinrich Hertz needs no introduction. A hundred years ago today he was deep at work on what was to become the experimental verification of Maxwell's theory of electromagnetism. His work proved the existence of electromagnetic or radio waves, shattered the concept of action at a distance, posed problems for electrical science and paved the way for radio communications.

Hertz found himself in the foremost rank of world physicists, lauded in science publications and the popular press. He was just 31 years old and the new scientific megastar. Six years later he was dead. Blood poisoning had robbed the world of his genius.

ELECTRIC WAVES

Early in his investigations Hertz found that electric waves move with finite velocity along a wire. Oliver Lodge performed similar work at about the same time in London and both men had been anticipated by Wilhelm von Bezold in 1870.

But Hertz made another discovery which set him apart. He observed that if a piece of wire was formed into a circle, with only a tiny gap between the ends, a spark could be made to cross the gap whenever a spark discharge was produced at a nearby induction coil. This happened even when there was no physical connection between the two, provided the resonant frequencies were similar. He had transmitted and received electromagnetic radiation through the air.

Others had in fact made similar observations but they had not realised what it was they had seen, nor had they linked it with Maxwell's ideas. Uniquely, Hertz now had a thorough understanding of Maxwell's theory and a rudimentary transmitter and receiver with which to investigate its physical assumptions and predictions. It was a task he now set himself.

Early in a series of experiments performed in 1887 and 1888, he studied the effects of placing different dielectrics between the transmitter and receiver. Wood, sulphur, paraffin and asphalt were used and his results confirmed one of the basic principles of Maxwell's theory: the polarization of a dielectric by electromagnetic forces.

Next, by measuring the length of the electric waves and calculating the frequency of his oscillator, Hertz was able to calculate the velocity of transmission of the waves through air. It was close to the known value for the speed of light and the two were later shown to be equal. This was a momentous discovery.

Two schools of thought had arisen as to how magnetic and electric forces acted on objects with which they were not in contact. The action-at-a-distance school assumed instantaneous action. Maxwell and others assumed the forces were transmitted by action between neighbouring particles, rather like a train shunting. This takes time. Hertz had shown that, incredibly fast though electromagnetic radiation is, its velocity is finite. This fact killed the widely-held concept of action at a distance.

Also in 1887 he discovered the photoelectric effect (the increase in current caused in some materials by incident light). He left its further examination to others, even though he recognized its importance. His goal was to test Maxwell's electromagnetic theory of light.

Demonstrations of standing waves, polarization, interference and diffraction followed. By the end of 1888 Hertz had proof that, like light, electromagnetic radiation is propagated as waves.

Walls covered with zinc sheeting reflected the radiation and enabled standing waves to be produced by interference between the incident and reflected waves. A 100kg prism of hard pitch was used to obtain refraction. Parallel wires arranged as a grating polarized the waves, a phenomenon which could also be achieved by reflection from the wall. The waves cast a shadow when directed at tin foil or gold paper and this demonstrated their ray-like properties. A screen with a hole in it produced diffraction.

Hertz had even found that the electric and magnetic fields oscillated at right-angles to one another.

EQUIPMENT

His equipment was modified several times and it is impossible to know exactly all the frequencies at which he worked, although estimates have ranged from 50 to 500MHz, in what are now the v.h.f. and u.h.f. bands.

For the final set of a long series of experiments the transmitter (or primary conductor as Hertz called it) consisted of an adjustable spark gap, set at 3mm, in the middle of a 26cm long brass dipole. The poles of the spark gap were formed by two spheres and fed by a small induction coil. A parabolic reflector was made from a zinc sheet two metres square. This simple and elegant device was held together with paper, wood, sealing wax and rubber bands. It could be dismantled quickly for the frequently-needed repolishing of the pole surfaces.

The receiver, or secondary conductor, had a dipole aerial. Each arm was 50cm long. Two wires connected the arms to a tiny spark gap formed between a brass sphere and a fine copper point. A wafer spring and micrometer screw gave exceptionally fine adjustment to the spark gap.

With this simple equipment, for which he measured the wavelength at about 66cm (455MHz), Heinrich Hertz conducted experiments which led to a revolution in physics and a revolution in electrical communications.

HERTZ'S EDUCATION

Hertz was born on February 22, 1857 in Hamburg, the son of a prosperous barrister who later became a senator. He had three brothers and a sister, all younger than himself. His father's family was Jewish, a fact which drew the attention of the Nazis some fifty years after Hertz's death. Hertz himself was a Lutheran.

At the age of six he started school. Though he did not demonstrate much artistic or musical aptitude, by twelve his practical skills were such that he had his own workbench and wookworking tools. Later he acquired a lathe. These practical skills were to prove important in his career.

He also had a great aptitude for languages, coming first in his class at Greek and taking private lessons in Arabic.

When he was 18 he moved to Frankfurt to prepare for a career in engineering. It was the first of a series of moves.

Engineering was a career he never followed but a year was spent gaining practical experience and reading for the state examination. As a side interest he also studied natural science and mathematics, a hint of an internal conflict between the rival attractions of science and engineering.

There followed a short spell at Dresden Polytechnic and a year of military service with the railway regiment in Berlin. Then in 1877 he moved to Munich, planning to enter the Technische Hochschule. Instead, with his father's financial backing, he entered the University to begin an academic and scientific career. The mental tug of war between engineering and science had been settled.

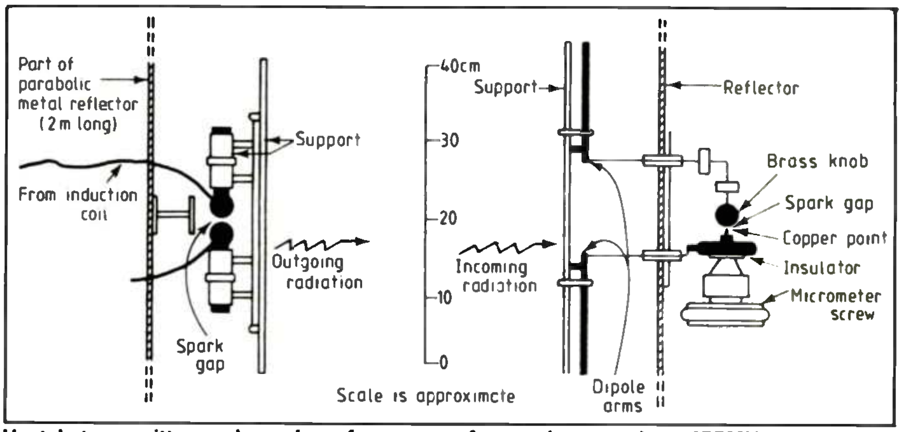
At Munich he alternated between theoretical and practical studies, a pattern which continued in his professional life. After a year he moved to Berlin to continue his studies, having also considered Leipzig and Bonn. Berlin was the right decision. It brought him directly into contact with Hermann von Helmholtz, a major figure in German physics and the man who was to become his mentor.

Immediately on his arrival in Berlin, Hertz was drawn by a prize offered to solve a problem concerning possible electrical inertia. Though a university student for only a year he decided to go for it. He won it by showing that electrical inertia, if any, is either zero or very close to it.

Helmholtz, who had suggested the problem, provided facilities and his own growing respect.

Helmholtz had by now suggested that Hertz try for another greater prize. This one was offered by the Berlin Academy for an experimental decision about the crucial assumptions of Maxwell's theory. Helmholtz was pointing his star student at a problem which would eventually make the student greater than the master. But Hertz turned away.

After writing his doctoral dissertation, which took him a mere three months, he became a salaried assistant to Helmholtz at the Berlin Physical Institute. It was a position he held for three years from 1880. He performed his duties, conducted research, published papers and attended scientific meetings which brought him into contact with the Germany's greatest physicists.



Hertz's transmitter and receiver: frequency of operation was about 455MHz.

The next career step for a budding university researcher was as an unpaid lecturer at the bottom of the hierarchy. This he undertook at the University of Kiel.

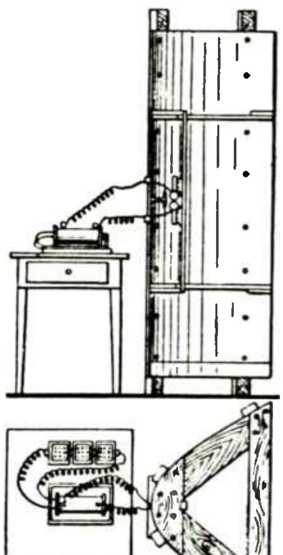
As Kiel had no physics laboratory, Hertz concentrated on theoretical work: meteorology, electric and magnetic units – and Maxwell's theory. This was his first deep study of Maxwell. Slowly everything was fitting into place.

KARLSRUHE

The lack of a laboratory at Kiel caused Hertz to turn down the eventual offer of a salaried position. So he moved again, his seventh move in eleven years, this time to the Karlsruhe Technische Hochschule as a professor of physics. He went there in 1885. The next year changed his life in two ways.

In the first half of the year he met Elisabeth Doll, the daughter of a colleague, courted her, and in July they were married. In November he began the experimental work which earned him his place in history.

Throughout he kept in touch with Helmholtz. Whilst at Karlsruhe Hertz published nine papers about his work on electromagnetic radiation. The ramifications of the discovery of the photoelectric effect he left for others to work through. In fact it was the future quantum theory which solved that particular puzzle and that was begun by Max Planck, the man who had succeeded him at Kiel.



The parabolic reflector arranged on a wooden frame. (After W.F. Magie: A Source Book of Physics, McGraw-Hill, 1935.)

In 1888 Hertz's fame was such that the university headhunters were after him. He refused an offer from the University of Giessen. Berlin wanted him as Kirchhoff's successor but in December it was the University of Bonn that succeeded in acquiring his services. Later Clark University in America approached him and the University of Graz tried to tempt him to become Boltzmann's successor. The tale is reminiscent of the transfer market for a modern-day football star.

In Bonn he lived with his family in the house where Rudolph Claussius had lived. He took on one research assistant – Philipp Lenard, who later won a Nobel Prize. More scientific papers and books followed.

By now Hertz had received many awards and medals by way of international recognition. One was the Rumford Medal of the Royal Society of London for which he came to England and was welcomed by the leading British physicists and electrical engineers.

Whilst at Karlsruhe Hertz had complained of toothaches. They were so bad that in the middle of his epic work one hundred years ago he underwent an operation on his teeth. The next year all his teeth were removed. Later he stopped work for a time because of nose and throat pains. Head operations followed and, understandably in an age of limited anaesthetics, he was often depressed. It would seem probable that he had a developing brain tumour but, whatever the cause, it was beyond his doctors' full understanding.

In the autumn of 1893 he worked on the last stages of his book on mechanics. This went to the publisher early in December. On December 7 he gave his last lecture.

At the age of 36 he still had much to offer, but he died on New Year's Day 1894. He was survived by his wife and two daughters, all of whom fled to England from Nazi Germany in 1937.

Next in this series of pioneers of electrical communication will be Alan Blumlein, the British electronics genius.